

**FINAL REPORT FOR NASA GRANT NAG5-3940
(1996-12-01 THROUGH 2001-11-30)****STELLAR OCCULTATION STUDIES OF PLUTO, TRITON, CHARON,
AND CHIRON**

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Bodies inhabiting the outer solar system are of interest because, due to the colder conditions, they exhibit unique physical processes. Also, some of the lessons learned from them can be applied to understanding what occurred in the outer solar system during its formation and early evolution. The thin atmospheres of Pluto and Triton have structure that is not yet understood, and they have been predicted to undergo cataclysmic seasonal changes. Charon may have an atmosphere—we don't know. Chiron exhibits cometary activity so far from the sun (much further than most comets), so that H₂O sublimation cannot be the driving mechanism. Probing these bodies from Earth with a spatial resolution of a few kilometers can be accomplished only with the stellar occultation technique. In this program we find and predict stellar occultation events by small outer-solar system bodies and then attempt observations of the ones that can potentially answer interesting questions. We also develop new methods of data analysis for occultations and secure other observations that are necessary for interpretation of the occultation data.

Notable scientific results from this program during the period covered by this grant (1996-12-01 through 2001-11-30) are: (i) a determination of the Charon/Pluto mass ratio (0.117 ± 0.006) from the astrometric data used for our occultation predictions; (ii) the detection of gaseous methane in Pluto's atmosphere; (iii) the development of a method for fitting occultation light curves to an arbitrary atmospheric model; (iv) the detection of global warming on Triton, (v) the determination that Triton's atmosphere is unexpectedly distorted from a spherical shape (most likely by high winds), and (vi) an accurate determination of the temperature profile for Triton's lower atmosphere that adds to the pioneering work of Voyager 2. This thermal structure indicates an unknown coolant at an altitude of 50 km.

Details of these results and other achievements are described in the publications listed in the next section—some of which (those marked with a *) are attached as reprints. In addition to the major results given in the previous paragraph, these publications present lists of occultation candidates and describe the results of our occultation predictions. They also describe the results of the related observations needed to interpret the occultation data and our participation in surveys for Kuiper Belt objects that will become our occultation targets in the future (in order to determine their diameters and search for tenuous atmospheres on the largest bodies).

Refereed Publications

*Chamberlain, D. M., and J. L. Elliot 1997. A Numerical Method for Calculating Occultation Light Curves from an Arbitrary Atmospheric Model. *Publ. Astron. Soc. Pacific* **109**, 1170-1180.

*Elliot, J. L., H. B. Hammel, L. H. Wasserman, O. G. Franz, S. W. McDonald, M. J. Person, C. B. Olkin, E. W. Dunham, J. R. Spencer, J. A. Stansberry, M. W. Buie, J. M. Pasachoff,

- B. A. Babcock, and T. H. McConnochie 1998. Global warming on Triton. *Nature* **393**, 765-767.
- *Elliot, J. L., M. J. Person, S. W. McDonald, M. W. Buie, E. W. Dunham, R. L. Millis, R. A. Nye, C. B. Olkin, L. H. Wasserman, L. A. Young, W. B. Hubbard, R. Hill, H. J. Reitsema, J. M. Pasachoff, T. H. McConnochie, B. A. Babcock, R. C. Stone, and P. Francis 2000. The prediction and observation of the 1997 July 18 stellar occultation by Triton: More evidence for distortion and increasing pressure in Triton's atmosphere. *Icarus* **148**, 347-369.
- *Elliot, J. L., J. A. Stansberry, C. B. Olkin, M. A. Agner, and M. E. Davies 1997. Triton's distorted atmosphere. *Science* **278**, 436-439.
- *Elliot, J. L., D. F. Strobel, X. Zhu, J. A. Stansberry, L. H. Wasserman, and O. G. Franz 2000. The thermal structure of Triton's middle atmosphere. *Icarus* **143**, 425-428.
- *Foust, J. A., J. L. Elliot, C. B. Olkin, S. W. McDonald, E. W. Dunham, R. P. S. Stone, J. S. McDonald, and R. C. Stone 1997. Determination of the Charon-Pluto mass ratio from center-of-light astrometry. *Icarus* **126**, 362-372.
- McDonald, S. W., and J. L. Elliot 2000. Pluto-Charon stellar occultation candidates: 2000-2009. *Astron. J.* **119**, 1999-2007.
- McDonald, S. W., and J. L. Elliot 2000. Triton stellar occultation candidates: 2000-2009. *Astron. J.* **119**, 936-944.
- Millis, R. L., M. W. Buie, L. H. Wasserman, J. L. Elliot, S. D. Kern, and R. M. Wagner 2002. The Deep Ecliptic Survey: A Search for Kuiper Belt Objects and Centaurs I. Description of methods and initial results. *Astron. J.* **in press**,
- Olkin, C. B., J. L. Elliot, H. B. Hammel, A. R. Cooray, S. W. McDonald, J. A. Foust, A. S. Bosh, M. W. Buie, R. L. Millis, L. H. Wasserman, E. W. Dunham, J. McDonald, L. A. Young, R. Howell, W. B. Hubbard, R. Hill, R. L. Marcialis, J. S. McDonald, D. M. Rank, J. C. Holbrook, and H. Reitsema 1997. The thermal structure of Triton's atmosphere: Results from the 1993 and 1995 occultations. *Icarus* **129**, 178-201.
- Stone, R. C., S. W. McDonald, and J. L. Elliot 1999. 5145 Pholus stellar occultation candidates: 1999-2005. *Astron. J.* **118**, 591-599.
- Stone, R. C., S. W. McDonald, J. L. Elliot, and E. Bowell 2000. 10199 (Chariklo) stellar occultation candidates: 1999-2005. *Astron. J.* **119**, 2008-2017.
- Trujillo, C. A., J. X. Luu, A. S. Bosh, and J. L. Elliot 2001. Large bodies in the Kuiper belt. *Astron. J.* **122**, 2740-2748.
- Yelle, R. V., and J. L. Elliot 1997. Atmospheric Structure and Composition: Pluto and Charon. In *Pluto and Charon* (S. A. Stern and D. J. Tholen, Ed.), pp. 347-390. Univ. of Arizona Press, Tucson, AZ.
- Young, L. A., J. L. Elliot, A. Tokunaga, C. de Bergh, and T. Owen 1997. Detection of gaseous methane on Pluto. *Icarus* **127**, 258-262.

*reprint attached